ANALYSIS OF NITRATE AND ATRAZINE IMPACTS IN THE TREASURE VALLEY SHALLOW HYDROGEOLOGIC SUBAREA

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Abstract: A project for the Idaho Department of Water Resources examines the relationships between land use and groundwater contamination of shallow aquifers in the western Snake River Plain of southwestern Idaho. Statistical analysis tools are used to analyze temporal and spatial data of nitrate and atrazine, and the results are represented in ArcMap and in graphical and tabular form to provide regional environmental quality managers. Even given the limited data available, the results suggest activities at the surface are reflected in nitrate concentrations in underlying groundwater. ArcGIS proves useful in analyzing temporal trends of groundwater quality and monitoring land use and contaminant levels. The results and methods of this study can be applied towards land use planning for this and other regions.

Introduction

Groundwater has been viewed as an inexhaustible, inexpensive, and invulnerable resource (Ground Water Quality Council [GWQC], 1992). These perceptions have led to the contamination of groundwater systems all over the world. Consequently, groundwater has come to be viewed as a limited resource that is relatively easy to contaminate but difficult to remediate (GWQC, 1992). The susceptibility of groundwater to contamination at any given location depends not only on the landuse/ landcover present at the location, but also the physical and environmental factors such as depth to groundwater, soil type, and the composition of the aquifer (Fritch et al., 1999).

Geographic Information Systems (GIS) are increasingly being used to forecast effects related to the spatial and time variability of data. These systems are expressly designed to store information about location, topology, and attributes of spatially referenced objects, and can also provide analysis of spatial properties of these objects (Leipnik et al., 1993). Due to its data handling capabilities, GIS is an effective tool in water resource management (Tsihrintzis et al., 1996). Attribute and spatial data developed using GIS allow the user to overlay coverages, analyze and determine pollutant loadings, and prioritize and identify critical areas in a very efficient and economical manner (DeBarry, 1991; Robinson and Ragan, 1993).

Given the perceived threat to human health, Maximum Contamination Levels (MCLs) have been established by the EPA for public drinking water. Primary MLCs, which apply to potential human health concerns, are, 10 milligrams per Liter (mg/L) for nitrate, and 3 micrograms per Liter (µg/L) for atrazine. They are used as yardsticks to assess the nitrate and atrazine concentration levels. (MCLs have been adopted by Idaho as Ground Water Rules (Idaho Dept of Health and Welfare, n.d.). Less than 2 milligrams per Liter (mg/L) is preferred for nitrates. IDWR considers nitrate levels over 2 milligrams per Liter (mg/L) to be indication of land surface impacts to ground water quality (Neely, 2005).

This research project is another step towards the evaluation of the relationship between ground water contamination due to nitrate and atrazine in the Treasure Valley Shallow Hydrogeologic region and certain land use category, using ArcMap 9.0 GIS platform. The research objectives involved: 1) Mapping the occurrence of nitrate and atrazine in certain land use category in the region. 2) Determining and examining the patterns of water quality variations over time, in the occurrence of nitrate and atrazine.

Study area

Figure 1: Study Area.

The study area - Treasure Valley Shallow Aquifer - is located in Ada and Canyon counties in southwestern Idaho. Sediments in the Treasure Valley are categorized in two general groups: the Idaho Group sediments and the Snake River Group sediments. Shallow aquifers in the area occur in the unconsolidated gravels and coarse-grained sands of the Snake River Group, while deep aquifers occur primarily in the Idaho Group (Neely and Crockett, 1998).

Research Methodology

This study was carried in two steps. The first one involved the use of Geographic Information Systems (GIS) in the creation of the database. The Arc GIS Map- version 9 was used to carry out the spatial analyses and to identify and display the groundwater regions sensitive to atrazine and nitrate pollution as a result of non-point sources. Different thresholds were established for nitrates on the basis of its concentration in the Treasure Valley Shallow subarea. A selection was made by banding their concentration attributes in to four distinct bands, <2 mg/L, 2-5 mg/L, >5-10 mg/L and >10 mg/L. The land use and land cover data for the Treasure Valley was developed by IDWR using image interpretation of scanned, geocorrected, and mosaicked CIR (Color Infrared) airphotos.

The second step used statistical analysis to determine the impact of nitrate and atrazine over time Since nonparametric tests usually have less restrictive assumptions than their parametric counterparts, they are ideally suited for detecting characteristics such as trends in environmental data (Hipel et al., 1988). SAS (Statistical Analysis System) was employed as the tool for conducting statistical analysis. This study used several levels of significance to compare the evaluation of the appropriate confidence level for mapping nitrate and atrazine trends for the ten annual sites, in the TVS subarea. In trend analysis, particularly involving water quality variations, it is common practice to accept a higher level of significance (lower Confidence Level) to test for the existence of a trend in exchange for a lower risk of overlooking trends that are present (increased power of hypothesis test). Maps at 90% confidence display even smaller areas of statistically significant change, i.e. at higher confidence level, there is a lower risk of mistakenly concluding it as a Type I error (that a change has occurred when it has not) while at the same time the complementary risk of a Type II error (of not identifying a change where it has occurred) increases. To be as conservative as possible on trend identification, a lower confidence level should be used (Welham and Merrick, 2004).

Discussion on Results

Nitrate Results

IDWR considers nitrate levels over 2 mg/L to be an indication of land surface impacts to the ground water quality (Neely, 2005). The majority (36%) of sites in the Treasure Valley Shallow Aquifer subarea recorded nitrate levels in the 2-5 mg/L category, followed closely (32%) by sites recording less than 2 mg/L and by sites (25%) recording 5-10 mg/L. Sites registering more than 10 mg/L comprised only 7% of those tested (Figure-7).

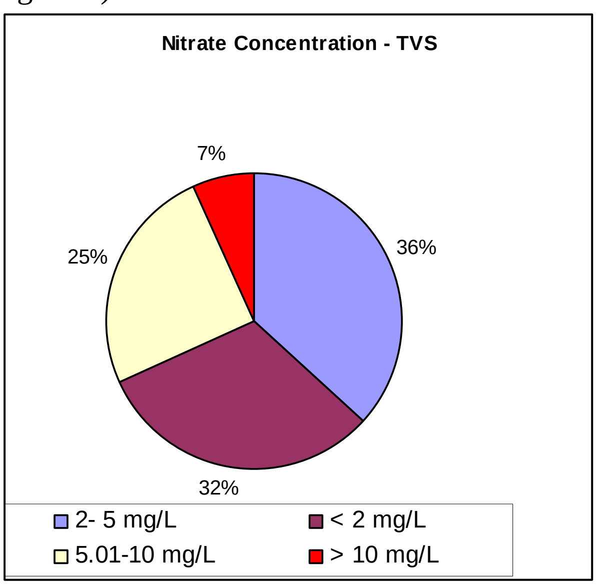

Figure 2: Percent of TVS Sites in Four Nitrate Concentration Ranges, 1990-2002.

Nitrate Results by Landuse

Landuse data from IDWR (2000) established that there are seven major Landuse Categories -Residential land, Agricultural Land, Rangeland, Water, Wetland/Riparian, and Barren Land, and Canal. However, to make the legend more concise, six landuse categories were established (Water and Canal were combined) and some of the subcategories were grouped together as well, for this project.

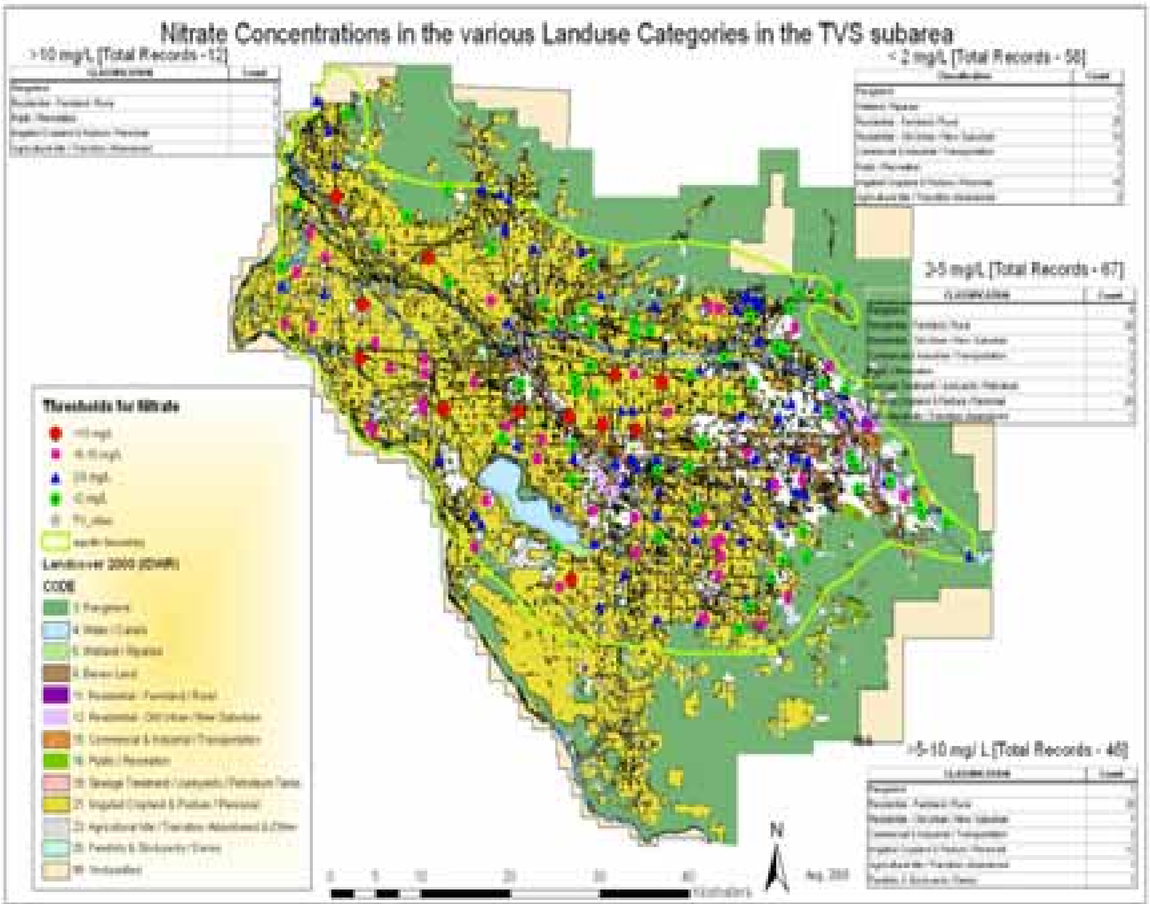

Figure 3: Nitrate Concentrations.

68% of the samples contained nitrate above the 2 mg/L level that IDWR considers to be the "impacted ground water" threshold. The highest concentration value for nitrate in TVS of 29.8 mg/L was reported in Wilder/Canyon County (MCL = 10 mg/L).

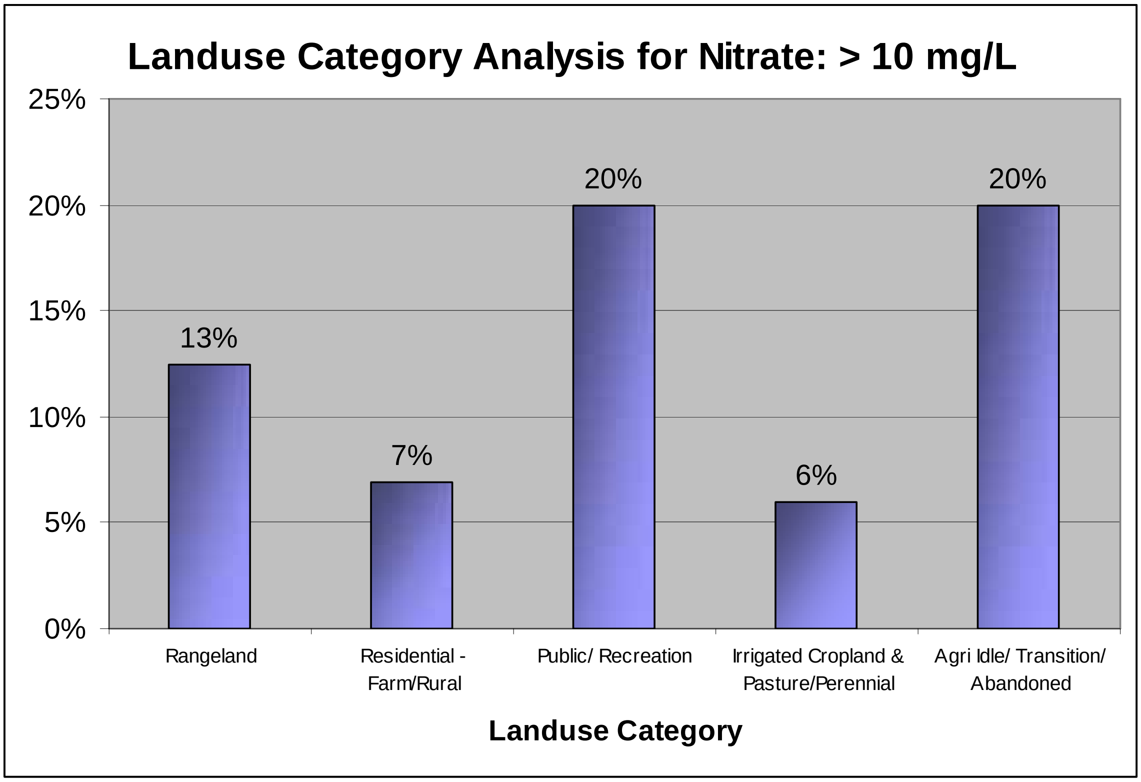

Figure 4: Nitrate Analysis: > 10 mg/L.

Public/Recreation areas and Agricultural Idle/ Transition/ Abandoned indicate 20% of the land under study had a nitrate concentration level of more than 10 mg/L. Public and recreation areas may account for a high level of nitrates because of large use of nitrate based fertilizers. Land under idle conditions or under transition will also indicate a high level of nitrates for similar reasons. What could be alarming is that the land that is under transition for housing or commercial purposes has concentrations above the MCL (10 mg/L).

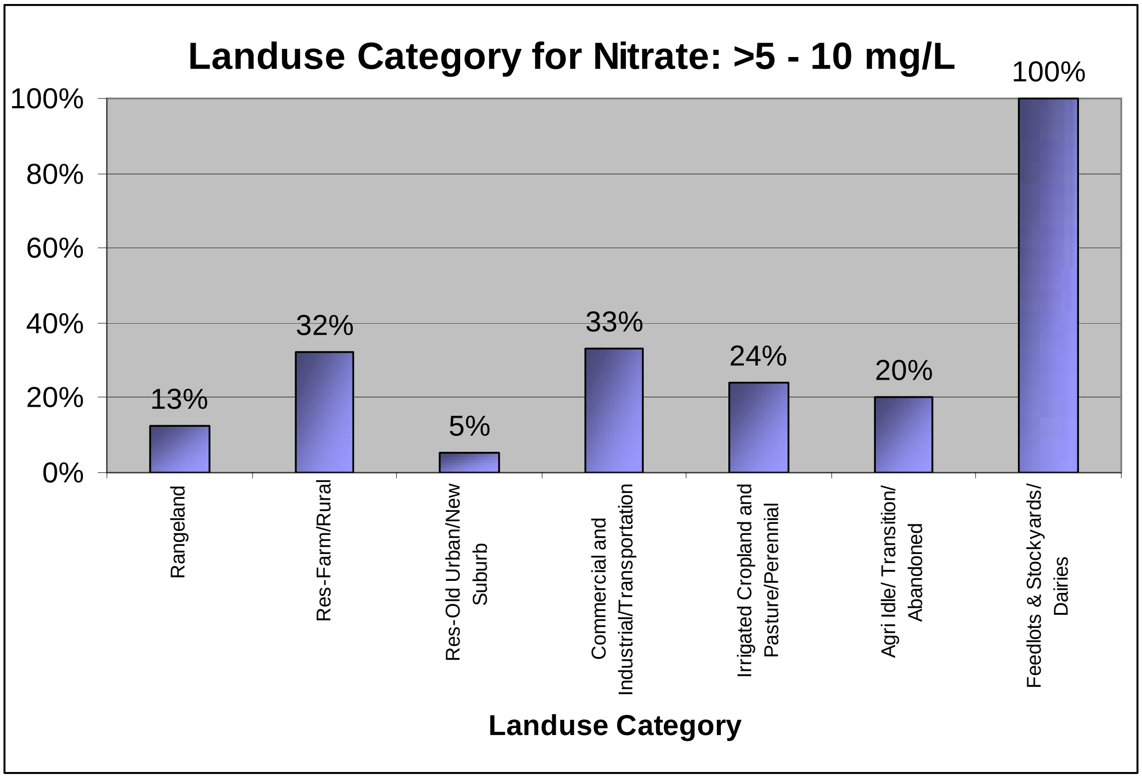

Figure 5: Nitrate Analysis: > 5 – 10 mg/ L.
*****100% indicates that all nitrate detections for the Feedlots & Stockyards/ Dairies category were in this concentration range only.

While Feedlots/Stockyards, and Dairies indicate 100% of the sites in this concentration zone, no conclusions can be made about them because only one site was reported in all the categories.

Commercial and Industrial/Transportation (33%) and Residential -Farmland/Rural (32%) are the two dominant landuse categories. While this is understandable for Residential – Farmland/Rural due to their proximity to agricultural areas where nitrate levels are expected to be high, it is not expected to be at these levels in Commercial and Industrial/Transportation. Further study is necessary to assess the reasons for such high concentrations in Commercial and Industrial/Transportation areas.

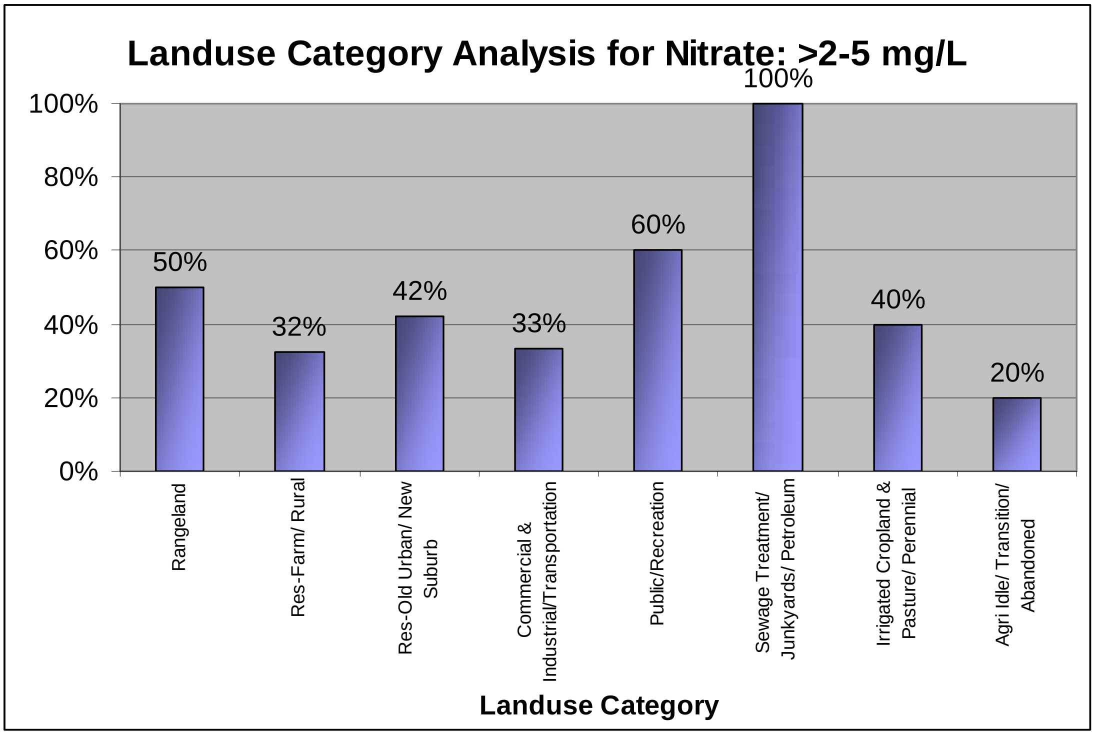

Figure 6: Nitrate Analysis: > 2-5 mg/ L.
***100% indicates that all nitrate detections for the Sewage Treatment/ Junkyards/ Petroleum categories were in this concentration range only.

Sewage Treatment/ Junkyards/ Petroleum indicate 100% of the sites in this concentration zone; similar to the results from feedlots, there is insufficient number of sampling sites to make a conclusion.

This concentration zone shows that all the landuse categories show a high percentage of occurrences compared to other concentration zones. This indicates that 2-5 mg/L of nitrate concentration is the most commonly occurring in the Treasure Valley Shallow subarea.

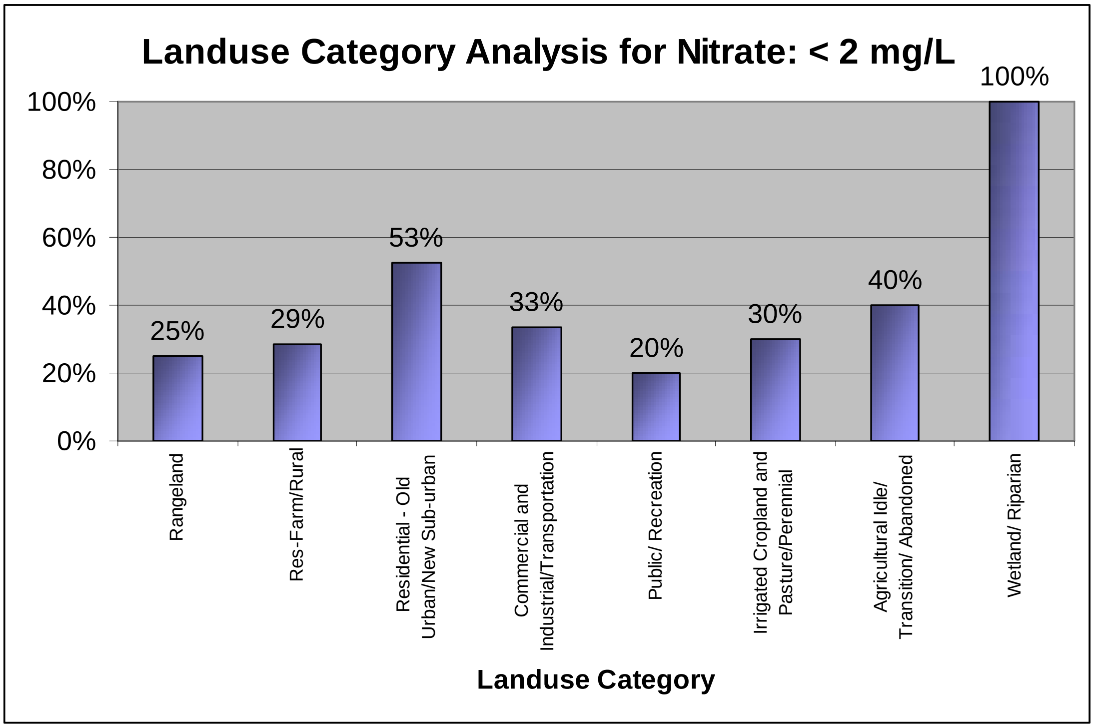

Figure 7: Nitrate Analysis: < 2 mg/L.
*****100% indicates that all nitrate detections for the specific landuse categories were in this concentration range only.

While Wetland/ Riparian indicate 100% of the sites in this concentration zone, sufficient conclusions cannot be made about them because only one site was reported in all the categories, which is too less to draw any conclusions.

It is noteworthy that most landuse categories have a low percentage of the land areas under this zone of nitrate concentration. This means that most areas in the TVS subarea have nitrate concentration levels of more than 2 mg/L. For example, only 20% of Public/Recreation areas indicate a nitrate concentration of less than 2 mg/L, which means that 80% of Public/Recreation areas have more than 2 mg/L of nitrates. IDWR considers land to be impacted if the nitrate concentration is more than 2 mg/L.

Atrazine Results

Concentration ranges for atrazine demonstrated that the maximum number of results are in the <=0.131 µg/L (88%) category, followed by the >0.131 - <=0.43 µg/L (10%) category, and lastly in the >0.43 µg/L (2%) category (Figure 8).

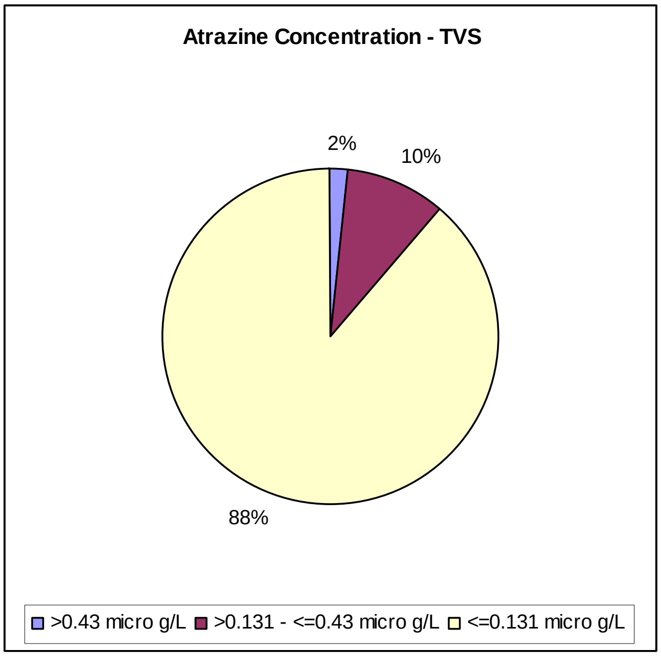

Figure 8: Percent of TVS Sites in Three Atrazine Concentration Ranges, 1990-2002.

Atrazine Results by Landuse

Atrazine concentrations varied from nil - 0.80 µg/L. Out of the 183 detection sites in the TVS subarea, the majority (88%) of the samples contained atrazine within the lower range of less than or equal to 0.131 µg/L (MCL = 3 µg/L). The highest concentration value for atrazine (0.80µg/L) was reported in Star (Ada County). The result indicates that atrazine concentrations vary from low to very low in the TVS subarea.

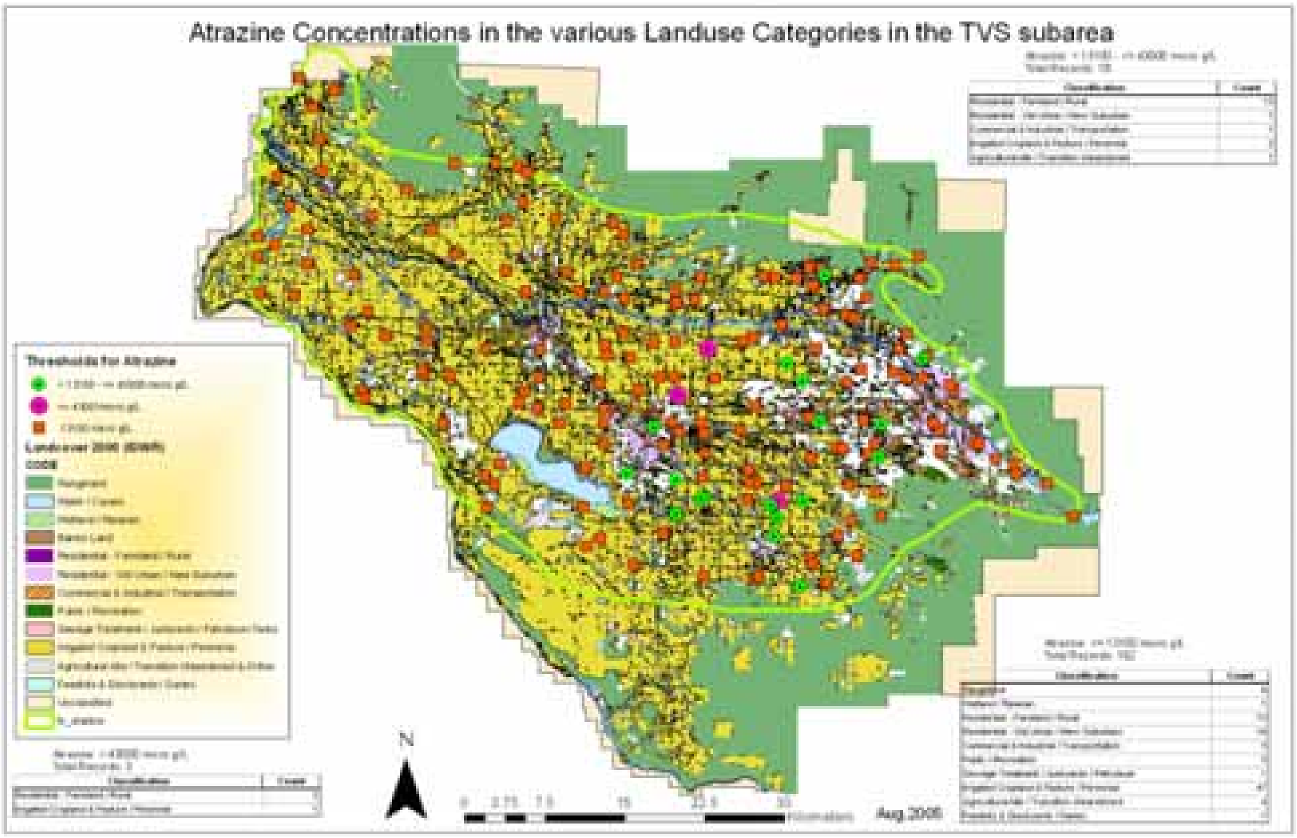

Figure 9: Atrazine Concentrations.

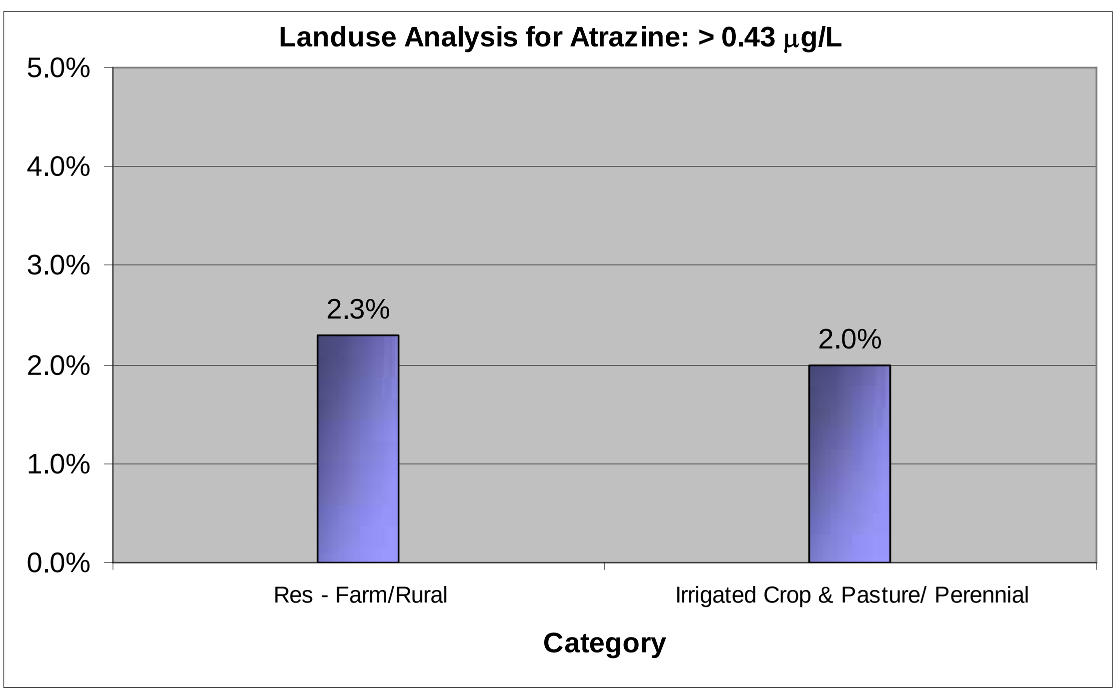

Figure 10: Atrazine Analysis: > 0.43 µg/L.

There are only two landuse categories that have atrazine concentration of more than 0.43 μg/L. The reason for occurrence of atrazine in these two categories can be attributed to the use of the herbicide in the cultivation of crops like corn, sugarcane, hay, pasture, and winter wheat.

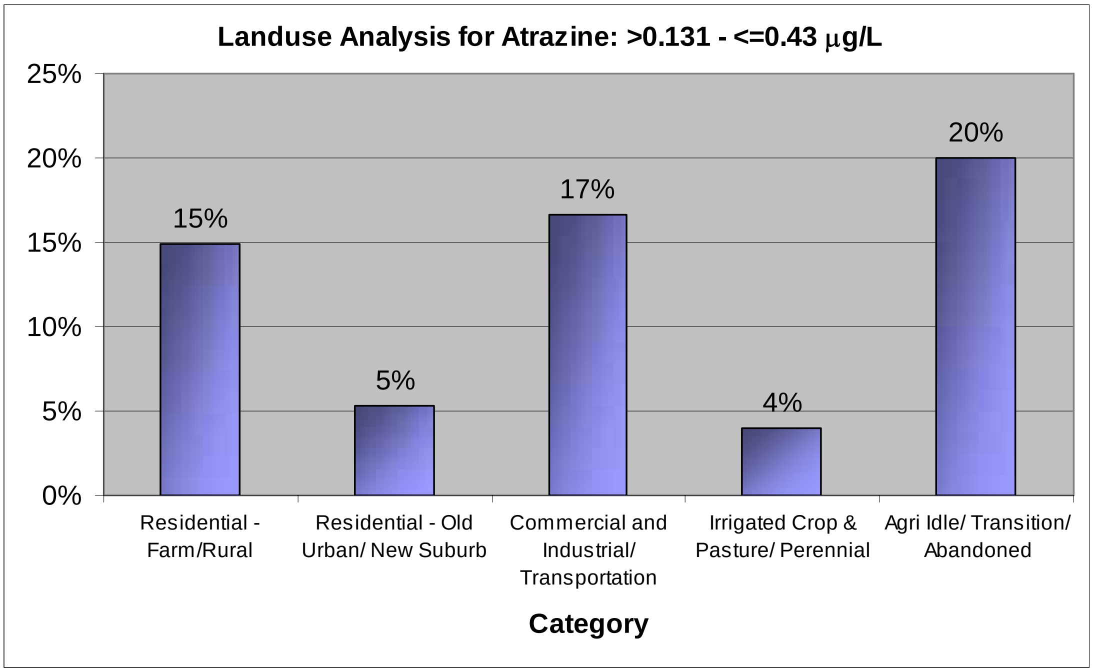

Figure 11: Atrazine Analysis: >0.131 to <=0.43 μg/L.

At these concentration levels the two most dominant categories are Agricultural Idle/Transition/ Abandoned/Other (20%) and Commercial and Industrial/ Transportation (17%). However it must be noted that only 18 sites out of a total of 183 sites are found to be in these landuse categories. This indicates that overall dominance of any category cannot be established under any of the landuse categories at this concentration level.

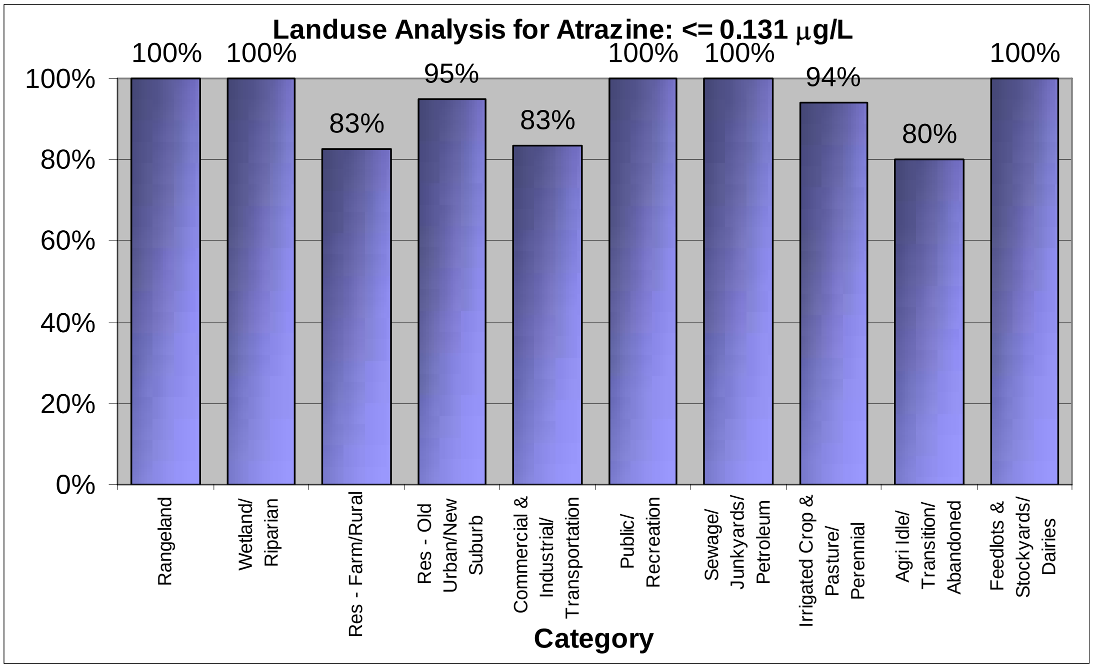

Figure 12: Atrazine Analysis: <= 0.131 μg/L.
*****100% indicates that all atrazine detections for the specific landuse categories were in this low concentration range only.

Most atrazine concentrations in the various land use categories fall under this zone (less than or equal to 0.131 μg/L). This indicates that atrazine concentrations are mostly in the very low range in the TVS subarea and currently they do not pose a threat to the region, but they should be monitored closely.

Trend Analysis for the Annual Sites

This project used the 10 annual sites for The Treasure Valley Shallow subarea, comprised of Notus, Meridian (two sites), Boise South, Lake Lowell, Cloverdale, Eagle (two sites), Middleton, and Wilder. The dominance of gravel and sand in the TVS subarea aquifers (both confined and mildly confined) indicate a resource that is vulnerable to anthropogenic contamination. It is also evident that majority of the wells (8 out of10) in the TVS region were found to be domestic, while the two wells in Boise South, and Eagle in Ada County served as public supply wells. The null hypothesis (Ho) was that there is no trend. At 95% Confidence Level, no trend was observed, while at 90%, only one site in Eagle (Ada County) showed a negative trend which meant that the concentration of nitrate has declined from 1996 to 2004. For the rest of the nitrate data, there was no trend detected at the 90% Confidence Level. However at 67% Confidence Level, six sites Lowell (Canyon), Meridian (Canyon), Cloverdale (Ada), Eagle (Ada), Middleton (Canyon), and Wilder (Canyon) showed a trend with only one site in Meridian (Canyon) showing a positive trend while the rest indicated a negative trend.

Table 1: The Multi Test Procedure for Nitrates.

The Multi Test Procedure – Nitrates								
N = 9		**p-Values – Nitrates**					**Confidence Level**	
Site ID	City/County	Raw	Stepdown Bonferroni (Corrected)	Hochberg (Corrected)	False Discovery Rate (Corrected)	Temporal Trend	90% Significant (Yes/No)	67% Significant (Yes/No)
43283511	Notus/Canyon	0.865	1.000	0.865	0.865	Negative	No	No
43324011	Meridian/Ada	0.570	1.000	0.865	0.713	Positive	No	No
43340611	Boise South/Ada	0.309	1.000	0.865	0.441	Positive	No	No
43353111	Lake Lowell/ Canyon	0.188	1.000	0.865	0.312	Negative	No	Yes
43354511	Meridian/Canyon	0.112	0.893	0.865	0.312	Positive	No	Yes
43360111	Cloverdale/Ada	0.088	0.789	0.789	0.312	Negative	No	Yes
43412111	Eagle/Ada	0.007	0.072	0.072	0.072	Negative	Yes	Yes
43420011	Middleton/Canyon	0.154	1.000	0.865	0.312	Negative	No	Yes
43431311	Wilder/Canyon	0.188	1.000	0.865	0.312	Negative	No	Yes
43433111	Eagle/Ada	0.699	1.000	0.865	0.777	Positive	No	No

Table 2: The Multi Test Procedure for Atrazine.

The Multi Test Procedure – Atrazine								
N = 8		**p-Values – Atrazine**					**Confidence Level**	
Site ID	Location	Raw	Stepdown Bonferroni (Corrected)	Hochberg (Corrected)	False Discovery Rate (Corrected)	Temporal Trend	90% Significant (Yes/No)	67% Significant (Yes/No)
43283511	Notus/Canyon	0.027	0.192	0.192	0.077	Negative	Yes	Yes
43324011	Meridian/Ada	0.048	0.232	0.192	0.077	Negative	Yes	Yes
43340611	Boise South/Ada	0.039	0.232	0.192	0.077	Negative	Yes	Yes
43353111	Lake Lowell/Canyon	0.260	0.521	0.521	0.298	Negative	No	Yes
43354511	Meridian/Canyon	0.750	0.750	0.750	0.750	Positive	No	No
43360111	Cloverdale/Ada	0.157	0.471	0.471	0.209	Negative	No	Yes
43412111	Eagle/Ada					Not Detected		
43420011	Middleton/Canyon					Not Detected		
43431311	Wilder/Canyon	0.039	0.232	0.192	0.077	Negative	Yes	Yes
43433111	Eagle/Ada	0.002	0.012	0.012	0.012	Negative	Yes	Yes

Once the p-values of the correlation coefficients for all ten wells for both nitrate and atrazine were obtained, they had to be adjusted for their inflated values, since the likelihood of a Type I error was high. The Stepdown Bonferroni method was applied to the raw p-values to make the corrections. This almost reversed the results for atrazine, but was steady for nitrate. The Hochberg method was also tried to make the corrections but the results obtained were very similar to the Stepdown Bonferroni method for both nitrate and atrazine. Another correction method called the False Discovery Rate (FDR) was applied to the p-values and this method gave results that were very close to the raw p-values for nitrate and atrazine. For nitrate all the three correction tests (Stepdown Bonferroni, Hochberg, and FDR) showed similar results, for all the ten sites.

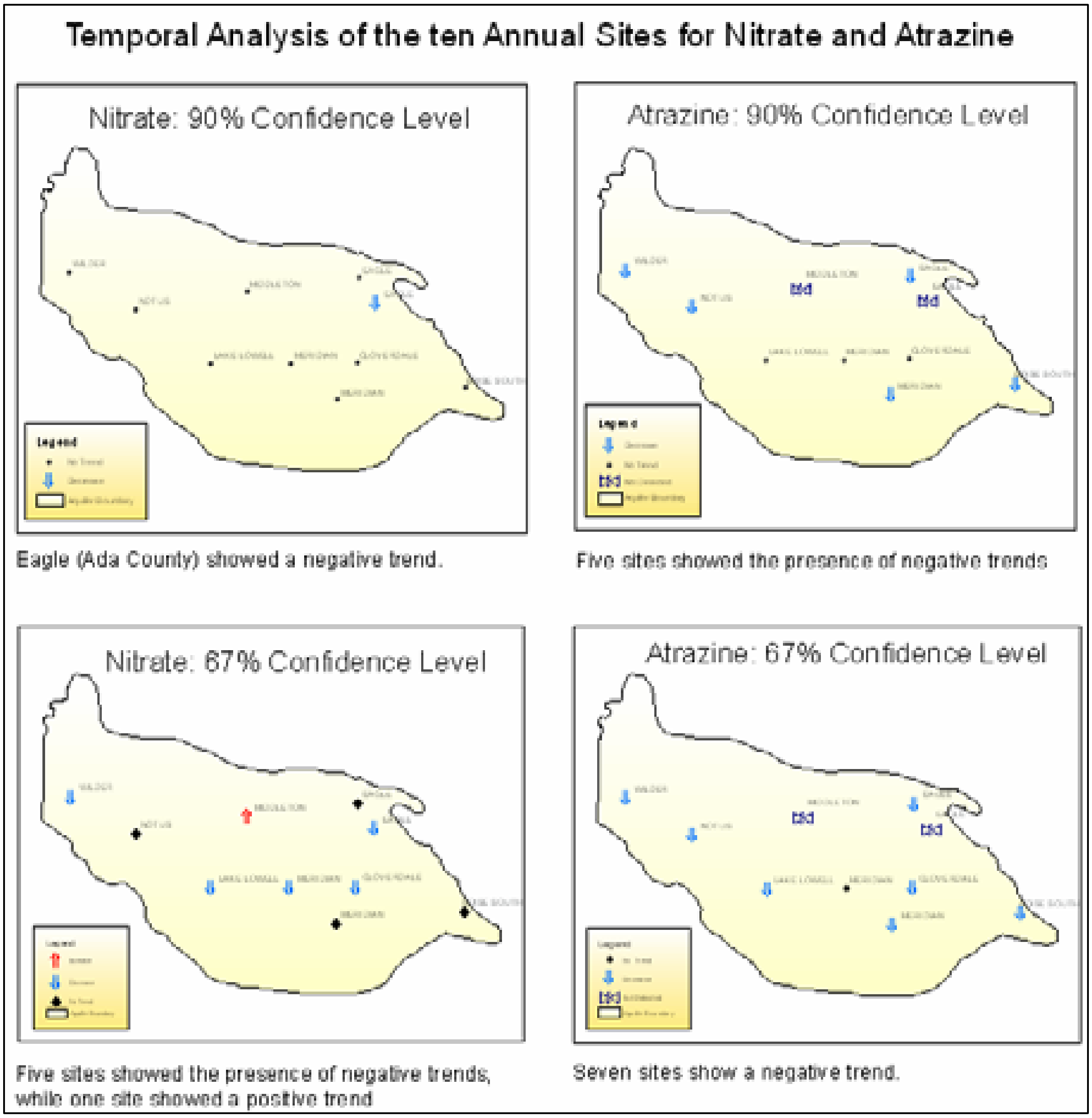

Figure 13: Temporal Analysis for Annual Sites in the TVS Subarea.

Level, seven sites show a negative trend. Based on the available data and the analysis done it can be said that atrazine levels are much below the MCL and the trends are declining in most of the sites in the TVS subarea during the years 1996-2003.

A statistical test (Pearson Correlation) was conducted on the ten annual sites by Neely, 2005, to evaluate temporal trends for nitrate from 1990 – 2004. Results from the test indicate that site 43360111(Cloverdale/Ada), and site 43431311 (Wilder/Canyon) showed a trend, consistent with the results obtained in this study.

Conclusions

The quality of groundwater for the TVS subarea based on the basis of 183 sampling sites for nitrates and atrazine, was found to be safe for human consumption and other beneficial uses at most of the sites. However, some sites had concentrations of nitrates that exceeded the MCL (10 mg/L). From the analysis done in this study for nitrate, it was concluded that the nitrate concentrations showed an indication of land surface impacts to the groundwater quality. Most of the sites reported the concentration of nitrate in the range of 2-5 mg/L. Atrazine detections are common in the TVS subarea and the results indicated that the concentrations were significantly lower than the MCL (3 μg/L) established by the EPA.

On carrying out the trend analysis on the ten annual sites, it was found that the values of atrazine are declining in the Treasure Valley Shallow aquifer over the period ranges from 1996 – 2003. At the 90% Confidence Level, five sites showed the presence of negative trends, while at the 67% Confidence Level, seven sites showed a negative trend. For nitrates at 90% Confidence Level only one site (Eagle/Ada County) showed a negative trend. However at 67% Confidence Level, six of the sites showed a trend, out of which five were negative, and one site showed a positive trend (Meridian/Canyon County. This definitely raises a cause for concern. The cause of this could be due to change in agricultural practices. Spearman's rank correlation method showed a weak correlation for most of the sites with only two sites showing a positive correlation, at 53% and 83% confidence level.

It needs to be evaluated if the yearly collection of samples is good enough for detailed analysis or does data need to be collected more frequently across seasons. However we have to take into account the cost and benefit associated with the collection of the frequent data. The maps may fail to show very accurate results for the selected groundwater sampling points. The accuracy of these maps could be increased with increase in the number of sampled locations. Data from 1992-1995 has a number of gaps both for nitrate and atrazine. As a result, the analysis was done where contiguous data was available (1996-2004). This made the data more limited in terms of numbers and could affect the statistical tests. The statistical analysis of water quality data for conducting a temporal analysis poses a number of challenges. They include the highly skewed distribution of data with occasional outliers and the presence of non-detectable values, such as the low concentration levels of atrazine.

There needs to be a policy regulating the usage of fertilizers and herbicides as farmers frequently over-fertilize and nutrient inputs to crops far exceed outputs (Buol 1995). It has also been shown that regulations on agricultural runoff are far less stringent than those placed on sewage treatment (Carpenter et al., 1998). Although the EPA is reevaluating the MCL standards for atrazine, it may be noted that many European countries have already banned the use of atrazine where the concentration has exceeded 0.1 μg/L. Hayes et al., (2002), reports that at levels of 0.1 μg/L and higher atrazine causes male tadpoles of African clawed frogs to develop both male and female organs. This concentration is 30 times lower than the MCL established by the EPA. This has caused a global decline in the population of amphibians

The landuse results and the trend results for the ten annual sites, for the TVS subarea provide useful information, which could be used by community planners, private individuals, and real estate developers. In the past, several development projects have been approved even without providing evidence for sufficient or uncontaminated ground water supply. However, data obtained in this project can impart valuable information, which could support decision-making and proper allocation of time, money and regulatory oversight to evaluate the potential ground water quality impacts of development in land use categories with respect to the current, and the changes over time in the occurrence of nitrate and atrazine levels.

Initiatives need to be taken to develop an outreach plan for communities to protect water resources in all possible ways, which includes emphasizing best practices in farms and agricultural management, well construction and maintenance, and year round monitoring of the wells. It is recommended that a more in-depth study of the Treasure Valley shallow Aquifer region be conducted for isolating the exact locations and the potential causes for the detections where MCLs were exceeded.

Acknowledgements

Data for the study was provided by Kenneth W. Neely, of Idaho Department of Water Resources (IDWR) for the project on impacts of nitrate and atrazine in the Treasure Valley Shallow Aquifer. Ken’s continuous insight and guidance throughout the project was of great help. I would also like to thank the members of my committee, Dr. David E. Wilkins, Dr. Sarah Toevs, and Charlla Adams, of the Boise State University (BSU), for their time, advice and support. I would also like to extend my thanks to Laura Bond, BSU, for her helpful suggestions and analysis in carrying out statistical tests, using the SAS tool.

Appendix A: Land Use & Land Cover Class Definitions

1. URBAN OR BUILT-UP LAND

#	Landuse Sub-Category	Description
11.	Residential -Farmstead/ Rural	*Farmsteads* are homes, generally isolated from other residences, associated with agricultural fields. This includes vegetable gardens, yards, barns, other out-buildings and storage areas. *Rural* residential is open, very light density residential. Lots are generally between one and five acres.
12.	Residential - Old Urban/ New Subdivision	*Old urban* is high-density urban residential land used for homes that are spaced closely, set back from the street, and arranged in orderly, rectangular patterns on lots less than 1/2 acre in size. Yards have mature trees. Includes high density categories such as trailer parks and apartments. *New subdivision* land is used for generally high density residences less than 20 years old. Houses are closely spaced, set back from the street and often are in non-geometric patterns. Cul-de-sacs are common. Trees are immature. Lot size is 1/8 to 1/2 acre.
15.	Commer-cial & Industrial Land/ Trans-portation	*Commercial & Industrial Lands* are used for manufacture, distribution and merchandising goods and services. Goods manufactured include small appliances, electronics and other secondary products. Merchandising areas include stores, offices, gas stations, restaurants, parking areas, motels and small warehouses. This land is usually located in strips along heavily traveled routes, in the core area in the center of a city or in large shopping centers. *Transportation* corridors include railroad rights-of-way and marshaling yards and major highways that do not follow Public Land Survey System lines.
16.	Public / Recreation	*Public* land are urban public land includes parks, colleges, churches, hospitals, cemeteries, schools and associated grounds; state and federal facilities. *Recreation* areas include golf courses, stadiums, driving ranges, race tracks, campgrounds and other areas for outdoor recreation.
19.	Sewage Treatment/ Junkyards/ Petroleum Tanks	*Sewage treatment* plants including settling ponds, lagoons, filter beds and associated buildings. *Junkyards/ Petroleum Tanks* include establishments involved in commercial development.

2. AGRICULTURAL LAND

#	**Landuse Sub-Category**	**Description**
21.	Irrigated Cropland and Pasture/ Perennial	*Irrigated Cropland* is land presently being irrigated, land irrigated during the present growing season or land fallowed either from water shortage or crop rotation. With the exception of alfalfa, crops grown are harvested once per growing season. A crop can be presently in the field, recently harvested or the field can be prepped for cultivation. *Perennial* includes orchards, vineyards and nurseries.
23.	Idle / Transition / Abandoned/ Other	*Idle* is land out of production for more than one season, but not permanently abandoned to agriculture. The irrigation infrastructure remains intact. *Transition* is the agricultural land that usually is in the process of being developed for housing, commercial use or other non-agricultural purposes. Generally the land has identifiable agricultural patterns, but is not prepared for a crop. Often, the land shows disturbance other than that associated with farming. The land is frequently found next to or mixed with land on which construction is occurring. *Abandoned* land taken out of production. Land cover may be annual weeds or young perennial shrubs. There should be some evidence of the land having been irrigated at some time in the past, such as stacked pipe, a faint circular scar or overgrown ditches. *Other* Agricultural land not otherwise described.
25.	Feedlot & Stockyard/ Dairy	*Feedlot & Stockyard* are land used for feeding, processing or warehousing of animals, such as cattle or sheep, bound for market. Includes pens, feeding areas, slurry lagoons, manure piles and associated facilities. This does not include any associated pasture or crop land. *Dairy* are land used for the purpose of dairy production from cows or goats. Includes barns, storage areas, feeding areas, slurry lagoons, manure piles and associated facilities. This does not include any associated pasture or crop land.

3. RANGELAND

Land that supports wild vegetation: grasses forbs, and shrubs. It may be grazed, but is not irrigated.

4. WATER/CANAL

Water are open bodies of water, including artificial lakes and ponds, reservoirs, settling ponds and rivers. This does not include sewage or slurry lagoons.

Canals include major feeder canals in the area. This includes the actual canal plus any associated right-of-way lands and roads that may be evident.

5. WETLAND/RIPARIAN

Land that is identifiable on mid-summer photography as being either wet or adjacent to a water-body.

6. BARREN LAND

Any land that is devoid of vegetation. This includes lave flows, sand and gravel bars and rock outcrops. Areas that have recently been scraped bare by heavy equipment should be called "Land in Transition"

Adapted from: Wilkins (2002).

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